Setting up a closed-loop test system for precisely controlled fuel injectors

The Perfect Dosage

In gasoline engines, the prerequisite for efficient combustion is a perfectly adjusted air/fuel mix. Continental has developed a new controlled injection system that always provides the exact fuel quantity needed throughout the entire life cycle of the engine. A test system from dSPACE enables precise testing in the lab.

injector coil and the moving injector needle. If the needle touches the needle seat, a characteristic current profile can be measured at the coil. The difference between the desired and the measured closing interval is used by the controller as the control deviation to determine the opening interval for the next power stroke. This type of control allows for even minute injection quantities with minimal tolerances. This significantly improves the fuel injection and stabilizes the combustion process. Both aspects are maintained throughout the complete life cycle of the components because of an adaptive control process.
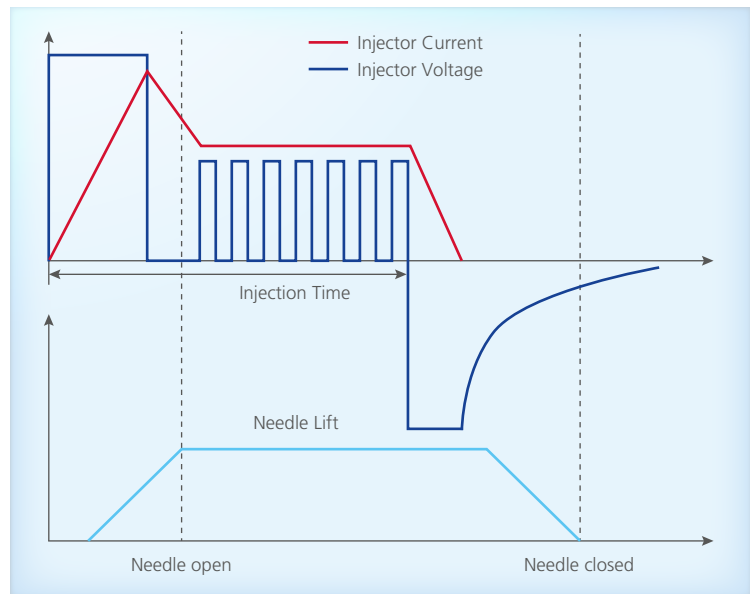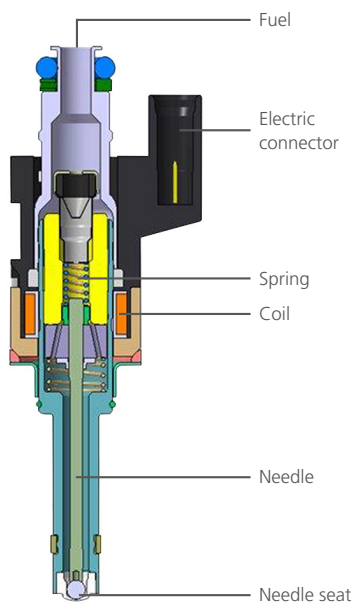
Validation Requirements

The validation of the EECUs with COSI function requires functional software tests for detecting the injector opening intervals. For this, the characteristic voltage and current curves of an injector under pressure must be simulated. It is not sufficient to use substitute loads or real parts because they are generally used for dry tests, in which no fuel is used. This means, the pressure variances in the intake manifold or the cylinder that are caused by fuel injection do not occur. Therefore, it is necessary to find a solution that can simulate the electric behavior of the injector in real time, taking into consideration the operating pressure at each working point of the engine. A special challenge is the extremely short opening intervals of the injectors that last only a few milliseconds. Because in this range of minute quantities even minor variances of the components used are relevant, the test solution must be sufficiently flexible with regard to their simulation but also easy to handle.

Tests with Virtual Injectors

The validation of EECUs is typically performed with hardware-in-the-loop (HIL) simulators. Therefore, it is only natural to aim for an expansion of the HIL simulators to test the

Stricter emission regulations lead to new challenges when developing spark-ignition engines. Therefore, new, innovative approaches in technology are necessary to help comply with ever more stringent emission thresholds. A particularly relevant aspect for the ideal air/fuel mix and efficient combustion is the exact dosage of the required fuel quantity. This process uses electrically controlled injectors that provide the needed fuel quantity by varying the opening and closing intervals of the nozzle. The intervals and current levels of the injector control influence the injection process. The fuel pressure also contributes to lifting the injector needle. The classic injection processes use precontrolled injection where the opening and

closing intervals of the injector are determined by the electronic engine control unit (EECU). However, mechanical manufacturing tolerances and the aging of the injector cannot be captured and corrected with this injection method. Thus, the actual opening intervals can vary over time, which leads to measuring variances. The automotive supplier Continental has now developed a process that helps measure and control the opening intervals and the injected fuel quantities.

Precise Injection with COSI

The sensorless evaluation system called Controlled Solenoid Injection (COSI) is specifically used to detect the closing time of the injector. The basis for this is the position-dependent inductivity, which is created by the

Left: Setup of a high-pressure magnet injector: The coil and the moving needle (magnetic core) create a variable inductance.
Right: Idealized representation of the injector control, needle lift, and injection time.

COSI functions. Because highly dynamic processes happen during a short time interval, the injector behavior can only be calculated fast enough if a field-programmable gate array (FPGA) is used. For the dSPACE SCALEXIO HIL systems that were set up in the test area, the solution that appeared most suitable was one that consisted of an FPGA Board (DS2655) and a newly developed electronic load module (EV1139) for each injector. The electronic load module is set up as a galvanically isolated interface to the EECU that is independent of the operating voltage. It emulates the real currents and voltages of the injector that is connected to the EECU. For this, it uses the injector behavior with inductive electric characteristics as

calculated by the FPGA model. The underlying open model from dSPACE can be precisely adjusted to the injector properties. The setup also supports other tests for electrical fault simulation, such as tests for short circuits and cable breaks. It can also generate functional faults to evaluate information from system behavior to emission values. To do this, the times for the early or late opening and closing of the valves can be manipulated. The influence of component variances and ageing can moreover be tested quickly in a simulation by parameterizing the relevant model components.

Use in a Project
The setup of a test system was driven both by Continental and dSPACE. The

first tasks included procuring information, clarifying patent-law-related questions and the creation of a requirements document. Based on these first steps, the companies developed a powerful prototype. The dSPACE developers were provided with access to fully set-up SCALEXIO simulators and ECUs to integrate the new COSI test solution. During the commissioning at the test lab, the test system was optimized for additional tasks:

- Precise single and multiple injection
- Accurate shifting of the injector closing times
- Parallel injection in two cylinder banks

The test system is now fully tuned and has since been firmly implemented

> "The sensorless Controlled Solenoid Injection validation procedure leads to high requirements for ECU testing. The SCALEXIO simulator and its expansion solutions can represent highly dynamic processes with precision and thus reliably validate ECUs."
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> *Michael Mench, Continental*
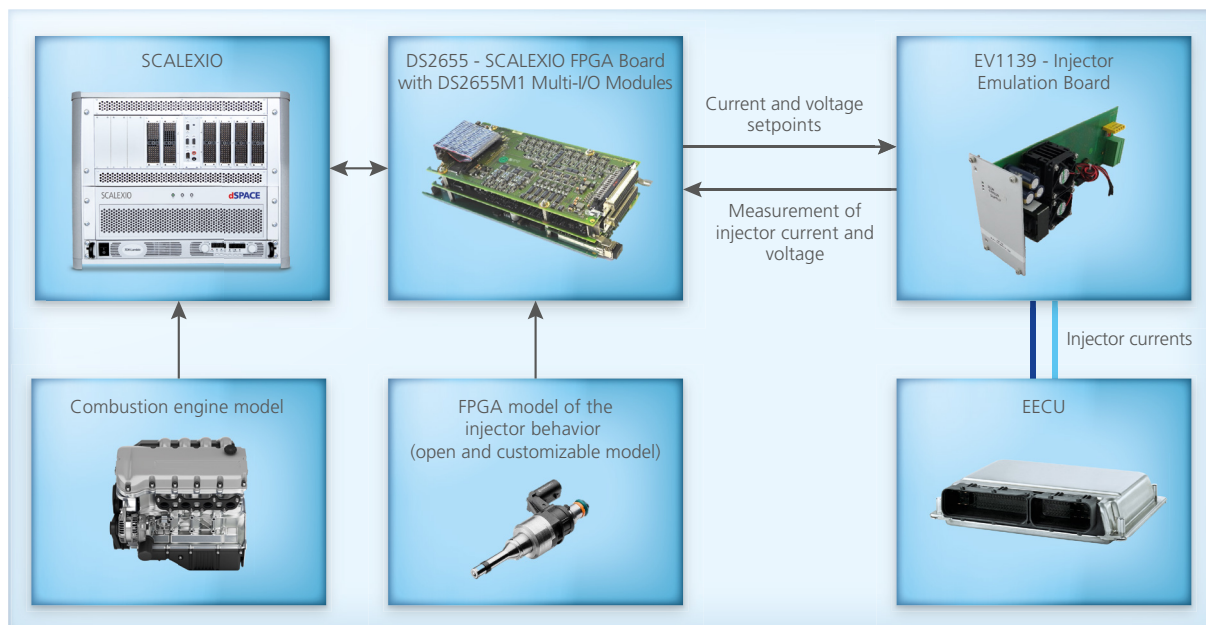
Setup of the SCALEXIO HIL simulator for the injector simulation: The combustion engine is simulated on the SCALEXIO Processing Unit. The injector is simulated with an FPGA board that controls the EV1139 electronic load module. The load, in turn, behaves like a real injector towards the EECU and inserts the real voltages and currents. It then returns the measured current and voltage values to the FPGA board.

in the validation process for EECUs. It has the flexibility and performance to verify the correct functioning of EECUs with COSI function in a closed loop and validate the requirements for the EECU software. At the same time, the diagnostic functions of the EECUs can be tested as well.

Figure 4: Comparison of the measured (above) and simulated injector currents as represented in dSPACE ControlDesk (below): The high congruence of both waveforms is instantly visible.
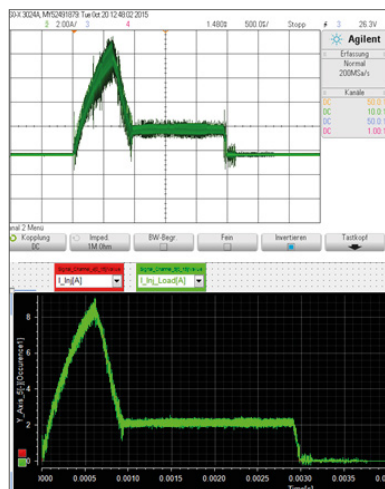
Summary and Outlook

Using controlled fuel injectors leads to new challenges when validating EECUs. To test and validate the controllers, Continental and dSPACE designed a new test solution. It simulates the injector behavior and emulates its real currents. A fast FPGA-based computation unit and an electronic load form the basis. This allows for operating the EECUs in a closed loop and thus for flexible testing in the lab. Currently, Continental uses the test system to validate the latest

generation of EECUs. Because the setup is highly flexible, it can easily be used for the development of future ECU functions. ■

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